Perturbed Continuum Approach to Predict the Dynamic Behavior of Metals

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Systems of various kinds that are subjected to non-equilibrium thermodynamic stimuli may incur irreversible damages leading to the breakdown of their functional capabilities. Often, the level of the damage is reduced and effectively counterbalanced through the redistribution of energy. We hypothesize that the energy rearrangement occurs along a well-defined thermodynamic path. At fixed positions of the path, the system maintains constant entropy. The positions are called the isentropic positions. An observer placed at the isentropic position may experience a rather smooth ride through the landscape of the thermodynamic system. However, the same ride monitored by an outside observer could appear as a quite violent event. Applicability of this hypothesis is tested for metals subjected to extreme loading rates. Our query is not so much whether a microstructural evolution occurs—we know that it does. Our interest is in answering a more fundamental question, namely what mechanisms necessitate the reconfiguration. For instance, a stressed metal develops a fairly regular array of dislocation cells, slip bands, and/or deformation twins. But it is not clear why the defects are so well organized at extreme loading rates. We investigate metal responses occurring within a very short time interval (in the range of 10^{-7}/ to 10^{-8}/s) [1,2]. For this reason, a linear form of the strength model

$$\sigma_{eq} = \left(\sigma_0 + \theta_h \, e_{eq}^p\right) + \theta_\psi \psi_{inc}$$

seems acceptable. In this relation, σ_0 is yield stress, θ_h is plastic hardening defined at nanoscale (thus homogeneous at mesoscale), the fluctuating (plastic) strain is e_{eq}^p, and θ_Ψ is dynamic hardening due to the formation of mesoscale defect structures. The rate of plastic strain is coupled with the formation of incompatibilities Ψ_{inc} in the field of particle velocity. Solution of the problem is obtained by satisfying the requirements of mass and momentum conservation. Expression for the dynamic overstress is found as a part of the solution.

A rather simple strength model with a built-in dynamic overstress is calibrated for copper and implemented into a 3D code. Several scenarios of the copper spherical shell either imploding or expending under constant pressure are investigated. The analysis suggests that the stress-induced defects lead to a highly non-uniform pattern of deformation, which is in turn associated with a differential temperature. The imploding shell at a pressure of 1 GPa and at t=5.63 ms is shown in Fig. 1. In the second case, an identical shell is subjected to a constant tensile pressure equal to 1 GPa. At an advanced stage of deformation (t=6.033 ms), the stress-induced defects produce several hot spots leading to a breakup of the shell (Fig. 2).

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[1] A. Zubelewicz et al., *Phys. Rev. B,* **71,** 104107 (2005).
[2] A. Zubelewicz, *Mechanics of Materials,* in press (2007).

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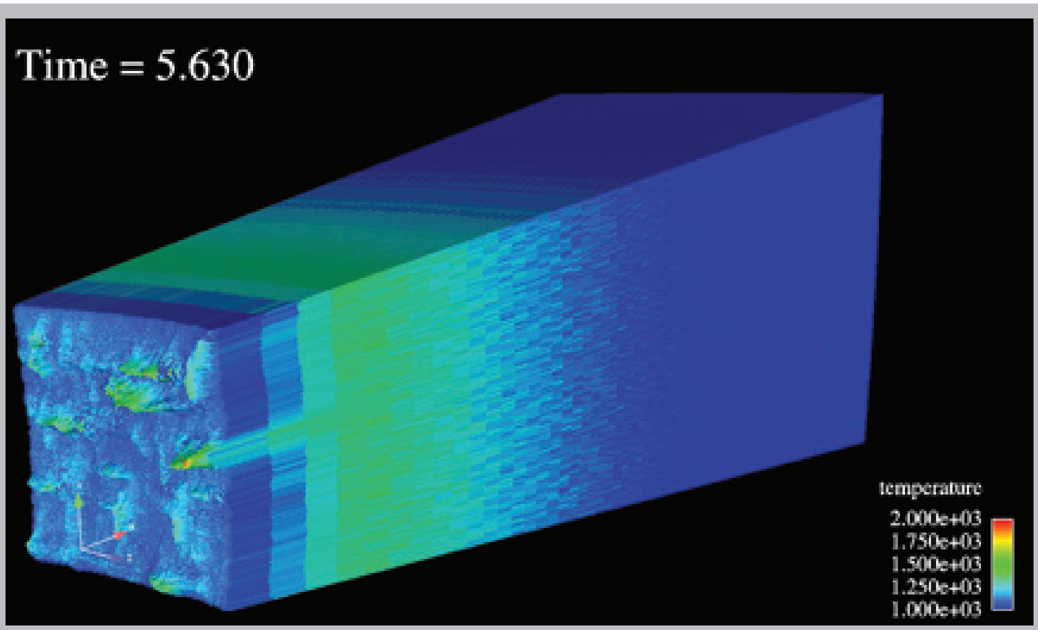

Fig. 1. Imploding spherical shell made of copper subjected to a constant pressure (1 GPa) at t=5.63 ms.

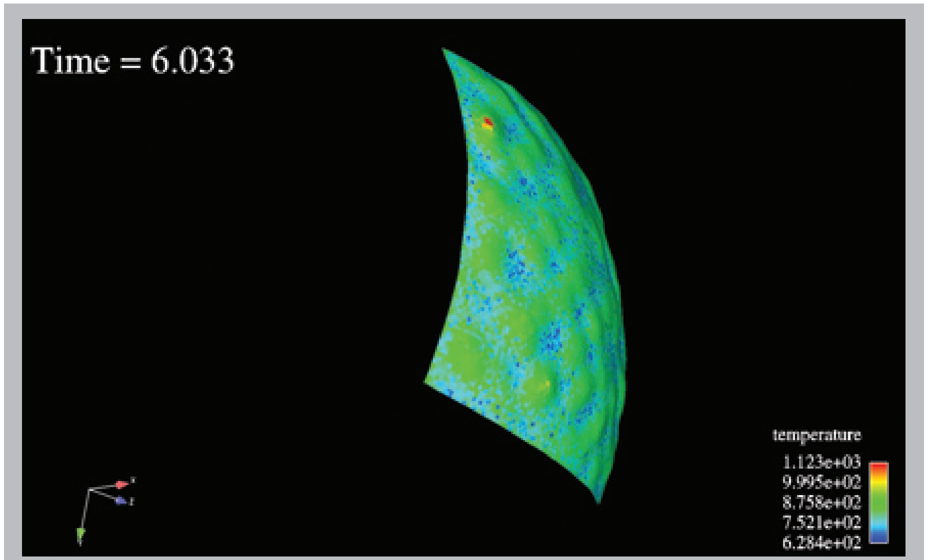

Fig. 2. Copper spherical shell at constant tensile pressure equal to 1 GPa and time t=6.033 ms.